THE EFFECT OF THE INSTRUCTIONAL SEQUENCE OF A COMPUTER SIMULATION AND A TRADITIONAL LABORATORY ON MIDDLE GRADE STUDENTS' CONCEPTUAL UNDERSTANDING OF AN ELECTROCHEMISTRY TOPIC

By

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Abstract of Dissertation Presented to the Graduate School
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The purpose of this study was to investigate the effectiveness of a computer simulation in terms of increased student conceptual understanding based on the instructional sequence, that is, as to when is the most appropriate time for a simulation to be presented to improve student understanding of a science concept. Many science educators feel that computer simulation offers tremendous potential for the enhancement of the teaching and learning of science concepts. Despite the advocacy of so many educators, research conducted over the past three decades on the effectiveness of instructional simulations has yielded mixed and less than encouraging results. In this study Science teachers and students in science middle school classes used a computer simulation and traditional teaching and learning methodologies to study the physical science topic electrochemistry. Group A students received the simulation (treatment 1) prior to the traditional laboratory experience (treatment 2), while Group B subjects received the computer simulation after traditional laboratory experiment. The study incorporated an analysis of covariance (ANCOVA). Although the results of this study did not statistically support the theory that prior use of a simulation before the traditional laboratory can improve learning, the treatment group completed the simulation activities before the actual hands-on lab performed slightly better on the achievement post-test than the other group.

CHAPTER 1
INTRODUCTION

Computer use in the classroom has become a popular method of instruction for many educators. This may be because software programs have advanced beyond the early days of drill and practice instruction. With the introduction of the graphical user interface, increased processing speed and affordability, computer use in education has finally become widely viable for mainstream educational purposes. Software designers are now able to design multidimensional educational programs that include high quality graphics, stereo sound, and real time interaction (Bilan, 1992). One area of noticeable improvement is computer simulations. Ellis (1984), Marks (1982), Nakleh (1983), Switzer and White (1984) stated that it is in the area of simulations that computers have the potential to deal with higher learning outcomes in a way not previously possible inside the science classroom. They claimed that simulation could potentially engage and enhance thinking in learners in science.

Simulations have been defined in the literature in different ways. In a broad sense, a simulation is defined as an abstraction or simplification of some real life situation or process. According to Thurman (1993) a common definition of the phrase "to simulate" means to duplicate the essential features of a task or situation. Alessi and Trollip (1991) provided the most comprehensive definition of computer simulations.

> In an educational context, a simulation is a powerful technique that teaches about some aspect of the world by imitating or replicating it. Students are not only motivated by simulations, but learn by interacting with them in a manner similar to the way they would react in real situations. In almost every instance, a simulation also simplifies reality by omitting or changing details. In this simplified world, the student solves problems, learns procedures, comes to understand the characteristics of phenomena and how to control them, or learns what actions to take in different situations. In each case, the purpose is to help the student build a useful mental model of part of the world and to provide an opportunity to test it safely and efficiently. (p. 119)

The educational benefits of computer simulations for learning are promising. There is evidence that simulations enhance students' problem-solving skills by giving them an opportunity to practice and refine their higher-order thinking strategies (Quinn, 1993). Computer simulations were found to be very effective in stimulating environmental problem solving by community college students (Faryniarz & Lockwood, 1992). In particular, computer simulation exercises based on the guided discovery learning theory can be designed to provide motivation, expose misconceptions in areas of knowledge deficiency, integrate information, and enhance transfer of learning (Mayes, 1992). In three studies, students using the guided version of computer simulation surpassed unguided students on tests of scientific thinking and a test of critical thinking (Rivers & Vockell, 1987). As a result of implementing properly designed simulation activities, the role of the teacher changes from a mere transmitter of information to a facilitator of higher-order thinking skills (Woolf & Hall, 1995). According to Magnusson and Palincsar (1995), simulations are seen as a powerful tool to teach not only the content but also thinking or reasoning skills that are necessary to solve problems in the real world.

A number of science educators feel that computer simulation offers tremendous potential for the enhancement of the teaching and learning of science concepts. Garcia (1995) cited several advantages of computer simulations compared to laboratory activities. First, there appear to be important pedagogical advantages of using computer simulations in the classroom. Second, the purchase, maintenance, and update of lab equipment are often more expensive than computer hardware and software. Also, there is no concern for students' physical safety in this learning environment. Akpan and Andre (1999) and Switzer and White (1984) discussed the place of computer simulation in the science classroom. According to these authors, the ultimate objective of computer simulation in the classroom is to enhance learning. In addition, the simulation's ability to provide opportunities for learners to develop skills in problem identification, seeking, organizing, analyzing, and evaluating. According to Duffy and Jonassen (1992) simulation is a cognitive tool for accessing information and interpreting and organizing personal knowledge. Gagne Wager, and Rojas (1981) indicated that simulations help students to identify relationships between components of a system and to learn to control such a system. Through simulation the learner is given the opportunity to practice on his or her own with a variety of situations which resemble "real-life" problems which he or she might face in the future. It is this type of practice, they indicate, which enhances the learner's problem-solving skills.

Simulations are used in most cases for unguided discovery learning. Students can generate and test hypotheses in a simulated environment by examining changes in the environment based on their input (Lee, 1999). Unlike the traditional classroom instruction in which students' roles are passive in most cases, this particular type of instruction may require students to become actively involved in learning.

Alessi and Trollip (1985) categorized simulations into the following four different types: (a) physical simulations, in which a physical object such as an electric cell is displayed on the computer screen, giving the student an opportunity to manipulate it and learn about it; (b) procedural simulations, in which a simulated machine operates so that the student learns the skills and actions needed to operate it; (c) situational simulations, which normally give the student the chance to explore the effects of different methods to a situation; and (d) process simulations, which are different from other simulations in that the student neither acts as a participant (as in situational simulations) nor constantly manipulates the simulation (as in physical or procedural simulations) but, instead, selects values of various parameters and then watches the process occur without intervention.

Gredler (1992) categorized simulations into two different types. Experiential simulations, which provide students with opportunities to develop their cognitive strategies because the exercises require that students organize and manage their own thinking, and learning by executing commands and carrying out complex problem solving in that knowledge domain. A second type of simulation is a symbolic simulation, which is dynamic in nature and represents the behavior of a system, or phenomenon, on a set of interacting processes. The students' role in symbolic simulation is that of principal investigator.

Despite the advocacy of so many educators, research conducted over the past three decades on the effectiveness of instructional simulations has yielded less than encouraging results (Lee, 1999). In an early evaluation effort, Cherryholmes (1966) reviewed the findings of six studies and concluded that, except for heightened interest, no substantial evidence could be found to support claims that simulations produce greater cognitive gains and affective changes than other methods of instruction. A decade later, Pierfy (1977) reviewed the results of 22 comparative studies and concluded that, in terms of fostering student learning, simulations were no more effective than conventional instruction methods. However, he found evidence that simulation supported the retention of information and changes in attitude. Using meta-analysis on the data from 93 simulation studies, Dekkers and Donatti (1981) failed to support Pierfy's findings concerning retention.

Leonard (1985) conducted a series of related studies on learning biological concepts from videodisc versus conventional laboratories. For the study of climate, the traditional hands-on (control) group studied these topics by manipulating graphs, charts, photographs, and maps. The experimental group used an interactive videodisc version that contained the same data as that used by the control group but, in addition, contained high-quality video motion sequences of organisms in major biomes of the world. The task for both groups was to infer life types, given climatic condition patterns. For the study of respiration, the experimental group studied the effects of temperature on respiration rate, as measured by the organism's oxygen consumption. Both groups were allowed 3 hours to complete each activity and write a laboratory report, which was subsequently graded. Both groups attended the same lectures and did the same assignments. The videodisc allowed the users to retrieve instant high quality "real life" simulated data while they were studying. The videodisc version also allowed students to manipulate the laboratory apparatus on screen. When the hands-on or videodisc activity was completed, each student completed a 3-page questionnaire. The questionnaire assessed the student's satisfaction with, interest in, and appraisal of the educational value of the activity. The two groups did not differ significantly in general interest, understanding of basic laboratory principles, or scores on laboratory examinations.

In support of simulations, Thomas and Hooper (1991) argued that

> simulations provide the learner with an environment to focus on without exacting control from the learner, offering unique learning opportunities in all subject areas insofar as simulations permit the attainment of learning goals that are beyond traditional and other computer based instruction methods. (p. 497)

White and her colleagues (White 1984, 1993; White & Horwitz 1987) developed a set of simulations called Thinker Tools. Thinker Tools provided a simulated environment that operated in a manner consistent with Newton's first law. Sixth-grade students who experienced Thinker Tools outperformed high school physics students who had just completed a unit on mechanics on a test on conceptual understanding of the first law. According to Andre and Haselhuhn (1995) simulation provides a potential means for providing students with experiences that facilitate conceptual development. Orlansky and String (1979) compared 30 empirical studies on military students' training achievement when either computer simulation instruction or conventional hands-on instruction was used. Their results showed that simulation not only produced equal or much better achievement gains but also required about 30% less time than the time required to complete the same course with conventional hands-on instruction.

Several explanations concerning the inconsistent results of simulation research have been offered. Poor research design is partly to blame (Butler, Markulis, & Strang 1988; Lee, 1999), but a much more serious problem appears to be the lack of a theoretical framework for the instruction use and evaluation of simulations (Bredemeier & Greenblatt, 1981). Salomon (1981) and Clark (1983, 1985) claimed that media research has asked the wrong questions that were based on faulty assumptions, leading to uninterpretable results. The inconsistency could be due to the different instructional roles applied to simulations in different studies (Gredler 1992; Jonassen 1988; Salomon 1981). Pierfy (1977) noted several design and research flaws in simulation studies. One of these weaknesses was that research studies compared simulations to classroom discussion types of instruction. Such comparison studies are not expected to bring about any meaningful results. If significant results were found, the differences were often misinterpreted (Clark 1983, 1985; Salomon, 1981). Sometimes research instruments fail to measure and report what they purport to measure (Dekkers & Donnati, 1981). Another possible problem is that comparison studies are not very appropriate or sensitive to the students' learning and achievement (Gredler, 1992). Another issue is that researchers have not focused on the key question of the conditions under which simulation is more effective or not effective and if there were some conditions under which students could earn benefits with simulation.

Brant, Hooper, and Sugrue (1991) argued that "(a) simulations establish a cognitive framework or structure to accommodate further learning in a related subject area, and (b) simulations provide an opportunity for reinforcing, integrating and extending previously learned material" (p. 469). Therefore, the effectiveness of a given simulation may depend upon when it is administered within an instructional sequence. According to Orbach (1977) and Thomas and Boysen (1984), simulations can fulfill two important instructional roles: (a) setting the stage for future learning and (b) providing an opportunity to apply or integrate newly acquired knowledge. As a stage-setting activity, a simulation is used prior to formal instruction, whereas as an application or integration activity, it is used after the instruction. A particular simulation might serve both functions, or it might be more effective when placed either before or after formal instruction.

Clark (1985) argued that precise criteria for the optimum use of simulations have not been established. Kulick, Kulik, and Cohen (1980) and Kulik, Bangert, and Williams (1983) reviewed a total of 51 primary studies concerning the effect of computer-based instruction, which includes studies on simulations. Kulick et al. (1983) reported the mean effect size as .49 for simulation from five studies. However, the review did not investigate the condition under which the simulation was more effective. The effect size never tells under what condition a student learns more, less, or none compared with the comparison group. For the instructional prescription, we need information dealing with instructional variables, such as instructional mode, instructional sequence, knowledge domain, and learner characteristics (Lee, 1999). According to Gokhale (1991), simulations used prior to formal instruction build intuition and alert the student to the overall nature of the process. When used after formal instruction, simulations offer the student an opportunity to apply the learned material. However, in reviewing the literature on the use of simulations in education, no study was found that measured the effectiveness of using the same simulation both before and after formal instruction.

This inconsistency of results encourages a more careful focus on the instructional role of simulations to develop meaningful learning environments. There is a need to investigate the source of conflict outcomes on the effectiveness of simulations in terms of different modes of presentation and practice and the appropriate instruction conditions under which they can be used.

Statement of the Problem

This study was designed to investigate the effectiveness of a simulation in relationship to instructional sequence, regarding when it is most appropriate for a simulation to be used in the instructional sequence. Specific questions related to the problem are as follows:

- Does the instructional sequence of simulations have an effect on student's ability to comprehend the intended learning? Specifically:
    - Do simulations used prior to traditional science laboratory have an effect in reducing common physical science content knowledge misconceptions?
    - Do simulations used after the traditional science laboratory have an effect in reducing common physical science content knowledge misconceptions?

Need for the Study

The pursuit of an understanding about the effectiveness of computer simulations in an education context is worthwhile for several reasons. Simulation potentially offers students opportunities to explore situations that may be impossible, too expensive, difficult, or time consuming to accomplish with actual laboratory or real-life experiences.

Even if real-life exploration is feasible, such experimentation can be supplemented by simulations that offer students the opportunity to explore a wide range of variables more rapidly. Such simulated experiences potentially can be used to confront alternative conceptions, produce disequilibration, and, with appropriate scaffolded instruction, lead students to a new accommodation (Piaget, 1983). In addition to being safe, convenient, and controllable, simulations may encourage students to participate actively in learning activities. Despite this potential for the use of simulations, empirical results examining the impact of simulations in science education have been mixed (Akapan & Andre, 1999). One potential way of resolving differences in existing research is to examine the ways simulations have been used in existing experiments. In most cases, simulations have been used as a substitute for laboratory experiments and, like most laboratory experiments, have followed didactic instruction on the topic.

Nevertheless, some theoretical perspectives suggest simulation may be more effective if used prior to formal instruction. The inconsistency of results in previous research encourages a more careful focus on the instructional role of simulations to develop meaningful learning environments. Overall, the significance of this study can be seen in the following ways:

- This study can provide new insight for understanding the effectiveness of a given computer simulation in relation to the sequence of the instructional activities.
- This study can generate empirically based results about the effect of using computer simulations prior to traditional middle school science laboratory experiences. As a result, educators and instruction designers would not need to rely on their intuition in deciding when to present the simulation in the instructional sequence.

- This study can generate empirically based results about the effect of using computer simulations after the traditional middle school science lab.
- This study can generate some guidelines for classifying the instructional functions for which simulation is used, and as a result educators and instructional designers could use simulations appropriately in the instructional sequence.

Hypotheses

The focus of this study was to discuss the effectiveness of simulation in terms of instructional sequence as to the most appropriate time for a simulation to be used. The following specific hypotheses were examined in this study.

Hypothesis 1. There are no significant differences between the pretest and post-test on test item #1 scores on knowledge of the electrochemistry concept involving the relationship between incomplete and complete conducting path for charges to move through a circuit for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #1 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 2. There are no significant differences between the pretest and post-test on the test item #2 scores on knowledge of the electrochemistry concept describing the relationship between surface area of the electrode and the voltage produced by an electrochemical cell for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #2 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 3. There are no significant differences between the pretest and post-test on test item #3 scores knowledge of the electrochemistry concept of two dissimilar metals being required as electrodes before an electrochemical cell may create a voltage for Group A, treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #3 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Assumptions

The results of this study are based on several assumptions that are listed below.

- The same grade subjects have similar prior knowledge of electrochemistry concepts.
- The subjects complete both the pretest and posttest in a serious manner and to the best of their ability.

Delimitations

The scope of this research study is delimited in several ways.

- The subjects are restricted to sixth-, seventh-, and eighth-grade students.
- The learning content is restricted to the field of physical science.
- The learning objective is limited to the comprehension level in the cognitive learning domain.

Limitations

The following limitations should be taken into account before the results of this study are generalized in any way.

- Since the present study utilized only a limited range of age, the results can only be generalized within this age range.
- Since the experimental treatments were short, the results may be affected by this time limitation.
- Since the simulation utilized only science concepts, the results of this study can be generalized only within this domain.
- The study was applied in the state of Florida, which affects the generalizations of the study to a larger population. Therefore, the findings are limited geographically and by characteristics of the sample.

Definition of Terms

The following terms have been defined to clarify their use in the study:

Accommodation is the act of grossly modifying an existing schema or creating a new schema to make space for new kinds of information.

The affective domain consists of behaviors corresponding to attitudes of awareness, interest, attention, concern, and responsibility; the ability to listen and respond to interactions with others; and ability to demonstrate those attitudinal characteristics or values, which are appropriate to the test situation and the field of study (Bloom, Masia, & Krathwohl, 1964).

A biome is defined as a major regional community of plants and animals with similar life forms and environmental conditions.

Comprehension refers to the ability to receive what is being communicated and make use of the material or idea being communicated without necessarily relating it to other material or seeing its fullest implication.

Critical thinking is purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, criteriological, or contextual considerations upon which that judgment is based.

Disequilibration is a state of cognitive dissonance or imbalance, which requires the act of accommodation in order to return to equilibrium.

In didactic instruction, the teacher directly tells the student what to believe and think about a subject. The student's task is to remember what the teacher said and reproduce it on demand.

Discovery learning theory is "an approach to instruction through which students interact with their environment-by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments" (Ormrod, 1995, p. 442).

Evaluation is to assess the credibility of statements or other representations that are accounts or descriptions of a person's perception, experience, situation, judgment, belief, or opinion and to assess the logical strength of the actual or intended inferential relationships among statements, descriptions, questions, or other forms of representation.

Graphical user interface is a computer working environment, such as Windows or Macintosh, that represents files and operations visually, using icons, buttons, windows, and other imagery that one can manipulate with a mouse.

Learning environment consists of the physical surroundings, psychological or emotional conditions, and social or cultural influences affecting the growth and development of an adult engaged in an educational enterprise (Hiemstra, 1991).

Learner control is a method in which learners control instruction during computer assisted/interactive hypermedia instruction. This includes time on task, instructional sequencing, presentation mode (video, audio, graphics, or text), amount of rehearsal, depth and breadth of study, and content type (rules, main ideas, example, or rehearsal) (Gay, 1986).

Higher-order thinking is thinking that takes place in the higher levels of the hierarchy of cognitive processing. Bloom's Taxonomy (1965) is the most widely accepted hierarchical arrangement of this sort in education, and it can be viewed as a continuum of thinking skills starting with knowledge level, comprehension, application, analysis, synthesis, and evaluation.

Instructional sequence is the order and organization of learning activities

Scaffolding is sometimes used to describe how teachers and more capable peers assist students to help them advance to the next level of performance or the next level of higher order thinking. Bloom's Taxonomy of Educational Objectives.

Instructional mode is the primary instructional methodology employed to convey knowledge between the teacher and the students in a particular class.

CHAPTER 2
REVIEW OF LITERATURE

The purpose of this chapter is to provide a summary and analysis of the professional literature related to the problem addressed in this study of the effectiveness of simulations in terms of instructional sequence. This chapter contains six major sections: (a) simulations in science instruction, (b) instructional simulations, (c) conceptual development, (d) simulations as preinstructional activity (e) simulations as postinstructional activity, and (f) multimedia instruction. Criteria used in selecting literature and synopses of the importance of the literature are presented. Literature related to the variables in the study are also presented in this chapter. Finally, a summary and implications of past research for design of this investigation are provided.

Simulations in Science Instruction

The pursuit of computer simulations in a science educational context is worthwhile for several reasons. Simulations potentially offer students opportunities to explore physical or biological situations that may be impossible, too expensive, difficult, or time-consuming to accomplish with actual laboratory or real-life experiences (animal dissection, electricity) (Akpan & Andre, 1999). Even if real-life exploration is feasible, such experimentation can be supplemented by simulations that offer students the opportunity to explore a wider range of variables more rapidly. Ellis (1984), Marks (1982), and Nakleh (1983) supported the fact that it is in the area of simulations that computers have the potential to deal with higher learning outcomes in a way not previously possible inside the science classroom.

Such simulated experiences potentially can be used to confront alternative conceptions, produce disequilibration and, with appropriate scaffolded instruction, lead students to a new accommodation (Piaget, 1983). In addition to being safe, convenient, and controllable, simulations may encourage students to participate actively in learning activities. Gagne et al. (1981) indicated that simulations help the learner to identify relations between components of a system and to learn to control such systems.

The Nine Events of Instruction, advanced by Robert Gagne, can be considered as a framework for approaching computer simulations. Gaining attention is the first level in the sequence of Gagne's theory. Through the use of multiple media (video, sound, animation, text, and graphics), instructional simulations as a preinstructional activity have the potential to captivate learners' attention. In addition, simulations can aid and stimulate prior knowledge, which is the third level in Gagne's learning events. Providing feedback to reinforce the learner is Level 7 in Gagne's theory. Probably one of the most beneficial features of a computer simulation is the ability to provide individualized feedback based upon actions of the learner. Assessing performance is Level 8 in Gagne's instructional sequence. Simulations provide a controlled environment in which performance can be monitored, and the learner can receive additional information in the form of instructive feedback. The final level in Gagne's theory is enhancing retention and transfer. The repetitive use of simulation, when used as a postinstructional activity, enhances the retention of knowledge gained in the classroom. Simulations have the ability to provide new tasks related to what have been learned, thus aiding knowledge transfer.

The purpose of this study was to investigate the value of computer simulations and determine when, in the sequence of instructional events, the simulation should be used. Science educators were chosen for the content of this study because of the significant use and study of the relationship between science learning and simulations utilizing modern computer technology.

Instructional Simulations

Research conducted over the past two decades on the effectiveness of instructional simulations yielded mixed results (Lee, 1999). In early evaluation effort, Cherryholmes (1966) reviewed the findings of six studies and concluded that, except for heightened interest, no substantial evidence could be found to support claims that simulations produce greater cognitive gains and affective changes than other methods of instruction. A decade later, Pierfy (1977) reviewed the results of 22 comparative studies and concluded that, in terms of fostering student learning, simulation was no more effective than conventional instructional methods. However, he found evidence that simulations supported the retention of information and changes in attitude. Using meta-analysis on the data from 93 simulation studies, Dekkers and Donatti (1981) failed to support Pierfy's findings concerning retention.

In support of simulations, Orlansky and String (1979) reviewed the results of 48 studies comparing military training simulations with conventional training and concluded that simulations produced equal or better achievement in about 30% less time. White and her colleagues (White 1984, 1993) developed a set of simulations called Thinker Tools. Thinker Tools provided a simulated environment that operated in a manner consistent with the Newton first law. Sixth-grade students who experienced Thinker Tools outperformed high school physics students who had just completed a unit on mechanics on a test of conceptual understanding of the first law. Frederiksen, White, and Gutwill (1999) showed that leading students through a graduated series of electricity simulations led to the development of dynamic mental models that facilitated understanding of electricity concepts.

In a study to determine the appropriate sequential placement of a simulation on genetics, Brant et al. (1991) compared three groups of students. One group used the simulation prior to the lecture on genetics; one group used it after the lecture; and one group did not use it until after the test. The group using the simulation prior to the lecture scored significantly higher than the control group. Those using the simulation after the lecture scored only slightly better than the control group.

Several explanations concerning the inconsistent results of simulation research have been offered. Poor research designs are partly to blame (Butler et al., 1988; Lee, 1999), but a much more serious problem is the lack of a theoretical framework for the instructional use and evaluation of simulations (Bredemeier & Greenblatt 1981). This inconsistency of results encourages a more careful focus on the instructional role of simulations to develop meaningful learning environments.

In his review of previous reviews, Lee (1999) divided simulations, based on their designs, to two forms—pure and hybrid—and further divided instruction to two modes—presentation and practice. The impure simulation incorporates expository instructional features, and the pure simulation does not have those features. The hybrid simulation mixes pure simulation and some features of expository instruction (providing the students with a large number of examples and a series of guidance together). Lee's review leads to the following conclusions:

- Within the presentation mode, the hybrid simulation is much more effective than the pure simulation.
- Simulations are almost equally effective for both presentation and the practice mode.
- Specific guidance in simulations seems to help students to perform better.
- When students learn in the presentation mode with the pure simulation, they showed a negative attitude toward simulation.
- Science seems to be a subject fit for simulation type of learning.

According to Orbach (1977) and Thomas and Boysen (1984), simulations can fulfill two important instructional roles—setting the stage for future learning and providing an opportunity to apply or integrate newly acquired knowledge. As a stage-setting activity, a simulation is used prior to formal instruction, whereas, as an application or integration activity, it is used after the instruction. A particular simulation might serve both functions, or it might be more effective when placed either before or after formal instruction. Precise criteria for the optimum use of simulation have not been established (Clark, 1985). Studies have been conducted in which simulations were used as either preinstructional or postinstructional activities. However, in reviewing the literature on the use of simulations in education, no study was found that measured the effectiveness of using the same simulation both before and after formal instruction.

Conceptual Development

Ausubel (1968) regarded the knowledge already existing in the cognitive structure of the learner as the single most important factor in determining whether or not knowledge will be learned and understood and how well it will be learned and understood. According to Piaget (1983), knowledge is constructed through action. Actions leading to impact or disconfirmation of expectations produce disequilibrium, and the learner may construct new mental images to resolve the disequilibrium. Bruner (1966) incorporated Piaget's theory into the idea that learning requires experiences at an inactive level before iconic and symbolic experiences can become real.

In his learning theory Ausubel (1978) attempted to explain how meaningful learning of concepts occur. He maintained that the important factor that affects learning is what the learner already knows and how the learner relates new information to this knowledge. Learning occurs when new concepts are linked to a learner's existing concepts; new information is related to an existing concept in such a way that the concept becomes more elaborate; and integration between existing concepts takes place (Ausubel 1963, 1968, 1978). The following question can be asked: Do simulated science activities provide the appropriate environment for the learning of new concepts based on Ausubel's learning theory?

Simulations and Conceptual Change Model

If science concepts are to be learned, misconception must first be removed (Minstrell, 1982). Maloney (1985) suggested that curriculum should be designed around known misconceptions instead of around ideas thought to be important and generated by scientists. Misconceptions can result from deficiencies of curricula and methodologies, language usage, everyday experience, analogies, metaphors, examination papers, and textbooks that do not provide the students with suitable experiences to assimilate the new concept (Ivowi & Oludotun, 1987). These misconceptions can cause students difficulty in forming acceptable understanding of physics concepts, theories, and laws.

Osborne (1983) examined students' views about electrical phenomena including the elements and functioning of DC circuits. Osborne (1983) crystallized the following collection of mental models from young people's explanations of a circuit consisting of a light connected by two wires to a cell:

- a uni-polar model, in which electricity is considered to travel by a single wire to a light and none returns; the role of the second wire is unspecified, except that it does not conduct electricity;
- a clashing currents model, in which different electricities pass from the terminals of a cell or battery, come together violently and are consumed in the appliance;
- a circulating but not conserved model, and
- a circulating and conserved model.

Lockhart (2000) stated that electricity is possibly the most challenging and demanding unit for students to learn in their study of physics. He reported several reasons that make it difficult to learn. First, electricity cannot be seen; students cannot observe electric fields superimpose at a certain point in space or observe current flowing. Second, since electricity is presented as an element to be feared in the home, there seems every possibility that these fears may inhibit classroom learning. Based on Lockhart's reasoning, can computer simulations provide teachers with a safe, time-efficient, cost-effective instructional strategy that can provide students with the opportunity to clarify their misconceptions? If traditional instruction does not adequately affect conceptual change, then novel approaches are required (Tao & Gunstone, 1999).

Mayer (1981) argued that a simulation provided before instruction may function as a conceptual model that allows students to better understand and encode the didactically presented information. Students receiving such a model may be better able to recall the presented didactic information and to reason with the principles taught in transfer situations. Thus, students who receive a simulation after didactic instruction may find it difficult to make sense of the model with which to assimilate the instructional information. That being the case, during didactic instruction, students may not be able to encode given information into cognitive structure as well as those who had a prior simulation.

Carlson and Andre (1992) compared simulations to traditional text instruction as a means of overcoming student preconceptions about electric circuits. The participants (36 males, 47 females) were enrolled in introductory psychology courses. Two methods were used in this investigation. In the first method, students used traditional text (TT), which combined portions of two commercially available middle school/high school texts that covered basic electrical concepts. The conceptual change text (CCT) consisted of the TT plus sections that challenged students' preconceptions by presenting diagrams of possible circuits and asked students to predict, in writing, what would happen in the circuit and then presented evidence that countered typical preconceptions. The test consisted of two sections. The first section dealt with basic electricity and the second with the calculation of current and voltage. The simulation portion was a HyperCard stack that made it possible to design and test circuits. The simulation consisted of a short tutorial on using the mouse and the circuit simulation and simulation itself. Students were presented with the problems in building a circuit. The total posttest contained 66 multiple-choice items; 26 of those items asked conceptual questions about series circuits. Students who studied using CCT scored significantly higher than those studying using TT. More importantly, the simulation group also had a higher conceptual model score than the no simulation groups.

Chambers, Haselhuhn, and Berger (1994) compared a simulation experience to hands-on experimentation concerning acquisition of a scientific understanding of electricity. This study compared reading three versions of a text to reading combined with simulation or hands-on experience. In the first method, students were directed to use a Macintosh computer simulation in which they constructed simple electrical circuits in order to test their beliefs and predictions. In the hands-on approach, students used kits to build electrical circuits as a mean of testing their ideas about electricity. The data were collected in college classrooms and computer laboratories. There were five conditions of the text: traditional text only; augmented traditional text, consisting of the traditional text with an additional explanatory text, examples, and diagrams; conceptual change text which consisted of the traditional text and conceptual change features that activated and refuted typical misconceptions; conceptual change text with simulation which used the same text, but asked students to test their predictions about circuits by using computer simulation; and conceptual change text with hands on experience, which used the same text, but asked students to test their predictions by building circuits. Students were expected to write their predictions and observe what happened when they tested those predictions. Prior to the experiment, both groups completed a pretest with a diagram of a flashlight cutaway, and students were asked to explain how it worked. The students also completed a 4-item pretest consisting of slides of circuits and were asked to explain if the circuits would work. The students received an immediate and a delayed posttest that assessed conceptual understanding of electrical circuits. The posttest administered to the students consisted of circuits and noncircuits, and students were to show which circuits would or would not work and why.

Significant differences were found among groups with regard to acquisition of scientific knowledge about electricity. However, a comparison between genders within a condition showed that males scored significantly better than females in the traditional text and augmented traditional text groups. This result suggests that males had more experience and perhaps more interest in electricity than females, but the performance of males remained the same regardless of whether they had read the conceptual change text, traditional text, or augmented traditional text. The researchers reported that the females found the simulation easier and somewhat superior to the hands-on experience, thus leading them to speculate that the lower experience of females with building electrical circuits led to frustration with the hands-on method.

Andre and Haselhuhn (1995) compared students who completed either a Newtonian motion or a non-Newtonian computer simulation either before or after didactic instruction. Participants were students in an introductory psychology class. The independent variables were the type of computer activity (simulation or game) and the position of the computer activity (before or after reading the text). The two types of computer activities were a simulation designed to illustrate Newtonian principles of motion and commercial games with a non-Newtonian motion. The motion simulation allowed the student to explore the effects of applying impulse forces to a body at rest or moving in a particular direction of space. The computer games were given to students either before or after they read a text dealing with Newtonian motion. The control group was to read the text and then complete the posttest. Students were required to complete a 45-item questionnaire that asked questions regarding their sex, class year, academic major, and age. In addition, they completed a vocabulary test and six questions concerning their interest and experience in physics. All the students completed a 4-item multiple-choice motion knowledge pretest. A 45-item multiple-choice posttest that assessed student understanding of the concepts of rectilinear and curvilinear motion and transfer of the learning of Newtonian principles was also completed by the participants.

There was a significant difference in the posttest means found between the control groups in the simulation-before and simulation-after text conditions. It was also found that male students who engaged in a computer simulation lesson before reading the physics text performed better on a test of transfer knowledge than male students who completed computer games before reading text. This result was consistent with those obtained by Brant et al. (1991) who found that genetics simulation before lecture enhanced learning more than the same simulation after lecture. The results suggested that the use of computer simulations before didactic instruction in physics might be more effective for male students than for female students.

Zietman and Hewson (1986) investigated the effects of instruction by using computer simulation to diagnose and remediate alternative conceptions. The microcomputer simulation was used to evaluate the effectiveness of the conceptual change model of learning through the use of a computer simulation facilitating a change in the student's perceptions. The microcomputer presented two capabilities: A simulation experiment that identified the different conceptions that students hold and a practice test diagnosing the students' conceptions in respect to the anatomical functions and identity of the particular organs in the system. Their results indicated that simulation is effective and can credibly represent reality and that remediation produced significant conceptual change, particularly in those students holding alternative conceptions.

Students hold a variety of alternative conceptions about natural phenomena that may actively interfere with the development of scientific conceptualizations. In the search for ways to influence the conceptual development of learners, researchers developed computer simulations as possible vehicles for helping students learn and for effecting conceptual change (Zietman & Hewson 1986). Overall, these results support the contention that computer simulations can be helpful in significantly altering students' misconceptions. The design of the simulation of this study incorporated the notion of building awareness of common electrochemistry misconceptions to help students overcome misconceptions.

Simulations as Preinstructional Activities

When used as a preinstructional activity, simulations can provide motivation; reveal misconceptions that would inhibit learning; provide an organizing cognitive structure of receiving new material; and serve as a concrete example of complex, abstract concepts (Thomas & Hooper, 1991). They simulate the manipulation and activation of relevant knowledge, which already exists within the learner's cognitive structure. The existence of this relevant prior knowledge has been shown to influence the learning of new material (Siegler, 1983). This influence is greatest for meaningful learning where existing knowledge often serves as an anchoring device or schema for evaluating and subsuming new pieces of information. Learning that occurs without reference to the prior knowledge of the learner is usually rote and arbitrary (Ausubel, 1968).

Hooper (1986) investigated a simulation of computer memory operations in which students performed specified tasks on the model as an initial experience in a beginning programming course. An analysis of selected programs written throughout the course indicated that students who used the simulation employed more sophisticated algorithm than students who did not use the model.

Taylor (1987) reported another study in which a simulation was used at different times during the semester. In Taylor's study, one group of students enrolled in a university sociology course used the simulation early in the semester; the other used it later. Three tests were given that revealed no differences. However, students who used the simulation early in the course had a more favorable attitude toward the simulation and its value.

Mayer (1981) documented the value of concrete models in creating anchoring knowledge to promote transfer as well as recall of conceptual ideas. Mayer's work covers the use of models in many disciplines involving the learning of computer programming.

He provided some students with a concrete graphic model of a computer and a brief description of how a computer works before providing programming instruction. The students exposed to the model revealed a greater ability to transfer the subsequently taught material than did students not receiving the model. Furthermore, when the same model was presented prior to formal instruction, it was effective; yet, when it was presented after instruction, it was not effective.

Simulation as Postinstructional Activities

In contrast to preinstructional use, simulations used after instruction facilitate the integration and application (drill and practice) of recently acquired knowledge. Isolated facts, concepts, and principles are usually of little practical value to the students. These pieces of knowledge must be integrated into functional units and assimilated with other units in order to be useful (Thomas & Hooper, 1991).

Integrating programs are designed to aid the student in making the necessary assimilation. They are appropriately used in any situation where several knowledge elements have been learned independently and need to be applied collectively. They are frequently used to support the acquisition of diagnostic skills or processes. The effectiveness of integrating simulations is demonstrated in several studies using a variety of criteria. Boysen, Thomas, and Mortenson (1979) investigated a simulation of reading skill weaknesses used with preserves teachers. Two classes of elementary education majors received traditional classroom instruction on administering an informal reading inventory to diagnose children's reading weaknesses. The students were randomly divided into two groups. One used a simulation in which they diagnosed simulated children's reading weaknesses. A second group received no formal integrating instruction. Significant differences favoring the simulation group were found on a 16-item test of analysis and procedure questions. The second group then used the simulation, and a second posttest revealed no significant differences. Although the simulation required several selections and decisions to be made, explicit feedback was not provided until a case was completely diagnosed.

Using a simulation created within Logo, Thompson and Wang (1988) investigated the learning of Cartesian coordinates by sixth-grade students. Two classes participated in the study, which was conducted after the students had completed a traditional unit on coordinates. One class used the simulation while the other class studied additional topics in mathematics. Following the treatment, a posttest was given that contained questions measuring knowledge and transfer. The class using the simulation scored significantly higher on both kinds of questions, but the difference was much greater on transfer questions.

In a study of simulated experiments in physics, Hughes (1974) combined simulation with actual lab experience to maximize the results. Three groups of students were compared. One group used physics lab equipment. One group used equipment to collect one set of data and used a computer simulation to control variables and collect the rest of the data. The final group used only the computer to generate the data for analysis. The laboratory-computer group was more successful on most measures. Using the lab to understand the problem and using the computer to produce the data was the most effective treatment.

Multimedia Instruction

Multimedia is the use of text, graphics, animation, pictures, video, and sound to present information. Since these media can now be integrated using a computer, there has been a virtual explosion of computer-based multimedia instructional applications. These applications range from serious computer-based tutorials for adults to the new category of "edutainment" products for children. The question that can be asked is whether multimedia applications can help people learn.

A good place to start is the classroom. The current, standard form of instruction is traditional classroom lecture. It seems reasonable to compare learning when the information is presented via classroom lecture to learning when the information is presented via computer-based multimedia.

Meta-analyses (Bosco 1986, Fletcher 1989, 1990, Khalili & Shashaani 1994, Kulik et al. 1983, Kulik et al. 1985, Kulik, Kulik, & Shwalb, 1986) examined over 200 studies that compared learning information that was presented in a traditional classroom lecture to learning the same information presented via computer-based multimedia instruction. The students were in K-12, higher education, industry, and the military. The information that was learned included biology, chemistry, foreign languages, and electronic equipment operation. The control group usually learned the information via classroom lecture or lecture combined with hands-on equipment experience. The comparison group usually learned the information via interactive videodisc or some other kind of computer-based instruction. The researchers most often measured learning using tests of achievement or performance. Over this wide range of students and topics, the meta-analyses found that learning was higher when the information was presented via computer-based multimedia systems than traditional classroom lectures.

Another very significant finding was that learning appeared to take less time when multimedia instruction was used. For example, Kulik et al. (1983) found one study that recorded an 88% savings in learning time with computerized instruction (90 minutes) versus classroom instruction (745 minutes) and another study that recorded a 39% savings in learning time (135 minutes for computerized instruction versus 220 minutes for classroom instruction). Both studies involved computer simulation instruction in physics. Kulik et al. (1986) identified 13 studies in which students using computers mostly for tutoring learned in 71% less time than students in traditional classroom instruction. In a comparison involving eight studies, Kulik et al. (1980) found that computer-based instruction took about 2.25 hours per week while traditional classroom instruction took about 3.5 hours, a 36% savings in learning time. However, as impressive as these findings are, there may be other explanations for these results.

Multimedia and Dual Coding of Information

There is empirical support for concluding that multimedia information provides learning advantages in several situations. According to dual coding theory (Clark & Paivio, 1991; Paivio, 1991), information is processed through one of two generally independent channels. One channel processes verbal information such as text or audio. The other channel processes nonverbal images such as illustrations and sounds in the environment. Information can be processed through both channels. This occurs, for example, when a person sees a picture of a dog and also processes the word "dog." Information processed through both channels is called referential processing and has an additive effect on recall (Mayer & Anderson 1991, Paivio 1991). Learning is better when the information is referentially processed through two channels than when the information is processed through only one channel. Referential processing may produce this additive effect because the learner creates more cognitive paths that can be followed to retrieve the information.

Empirical multimedia studies support this idea. In the Mayer and Anderson study (1991), the students who heard a verbal description simultaneously with the animation (verbal and nonverbal channels) performed better on a problem-solving test than the students who heard the description only (verbal channel), saw the animation only (nonverbal channel), or got no training. The same researchers (Mayer & Anderson, 1991, 1992) also performed a series of studies in which an auditory explanation of a bicycle pump or an automobile brake operation was presented before or during an explanation showing the same information. The mechanically naive students who heard the explanation with the animation (combined verbal and nonverbal channels) performed better on a creative problem-solving test than the students who heard the verbal explanation before the animation (separate verbal and nonverbal channels).

In an exploratory study, Bell and Johnson (1992) allowed four people to select pictures or text for communicating instructions for loading a battery into a camera. Qualitative results showed a strong preference for pictures rather than text. The researchers believed that the information to be communicated was spatial and that the results supported the hypothesis that spatial information should be presented pictorially.

A study by Garrison (1978) supported the idea that spatial relations are recalled and recognized better by children when the spatial relations are presented via story text and illustrations rather than story text alone. Also, a series of studies by Dwyer (1967, 1978) found that illustrated text was better than text alone when students were tested on spatial information using a drawing test.

Pictures appear to be an effective way to learn spatial information. This may be because spatial information tends to be encoded spatially (Kosslyn, Ball, & Reiser, 1978) rather than verbally or by what it means (i.e., semantically).

In summary, a great deal of the literature shows that the type of medium is not as important as the content of the instruction, presentation format, and viewer expectations and characteristics (Clark & Salomon, 1986; Reiser & Gagne, 1982, Schramm, 1977). With this idea in mind, Reiser and Gagne (1982) proposed that future media should be selected on the basis of its appeal and efficiency, as opposed to assumed learning benefits. Computer simulations, therefore, should be grounded in pedagogical theory; be applicable to the target audience; and present content in a fashion that motivates, excites, interests, and encourages the viewer. The researcher designed Lord Kelvin simulations with these ideas in mind and was guided by research literature on conceptual change and development, simulations as instructional activities, and multimedia instruction.

CHAPTER 3
METHODOLOGY

The purpose of this chapter is to describe the design and methodology used to investigate the effect of order with respect to the presentation of a computer simulation and a traditional lab experiment. Quantitative methods were used to provide a picture of the conceptual change that occurs in the students. The investigation used an ANCOVA model design to answer questions about the benefits of ordering the simulation and the real lab experiment.

This study is a part of a project funded by National Institutes of Health (NIH) to produce computerized instructional materials to improve science learning in the middle school population and to provide educators with a low-cost, ubiquitous, hands-on technology, and experience by creating a data-centric educational environment that better simulates a "real-world" scientific setting consisting of protocols, procedures, data acquisition, visualization, analysis, and hypothesis formation.

Description of Setting

The settings for the study were public middle school science classes in the state of Florida. Two middle schools in Alachua County participated in the study. The first school was a rural middle school. This school has an "A" grade in the Florida School Indicators Report. The average class size for science Grades 6 to 8 is 26.4. The percentage of gifted is 10.4%. Teachers' average years of experience is 12.8 years. The per pupil expenditures are as follows: exceptional, $5,433; regular, $4,063; at risk, $4,056; vocational, $4,142; and free/reduced price lunch, 42.2%.

The second school was a suburban middle school. This school has a "C" grade in the Florida School Indicators Report, and the average class size for science Grades 6 to 8 is 27.1. The teachers' average years of experience is 13.4. The per pupil expenditures are as follows: exceptional, $4,804; regular, $3,756; at risk, $3,356; vocational, $4,005; and free/reduced price lunch, 33.3%.

Description of Participants

Participants were selected for the study from a sample chosen by the investigator as a representative sample of public school students and teachers in North Florida. Two schools in the Alachua County district participated in the study. The first rural middle school had 549 students. The percentage of white students is 72.5%; 24.2%, Black; 1.5%, Hispanic; 1.3%, Asian; .5%, Indian; and the pupil/teacher ratio is 17 in Grades 6 to 8.

The second middle school consisted of a larger, more suburban student population with 1,007 students. The percentage of white students is 59.6%; 29.2%, Black; 7.1%, Hispanic; 3.8%, Asian; 0.4% Indian; and pupil/teacher ratio is 21.00 in Grades 6 to 8. Seven middle school classes were randomly assigned to one of two experimental groups. The total number of the participants was 176 students.

Experimental Research Design

The research was designed as a pretest-posttest treatment study (Isaac & Michael, 1981). The study used an ANCOVA model design to provide quantitative data that could be used to answer questions about the order of the simulation and real lab experiment. The experimental design helped to answer questions about the effects of a treatment that varied only in the order of presentation. An ANCOVA was used to compare the item means on the dependent variable adjusted for the influence of a covariate. The covariate (pretest) was used to adjust for initial differences between the treatment groups since random assignment within groups was not possible. An ANCOVA was selected for use since it decreased error variance that increased the precision of the treatment effect estimates. This resulted in a more powerful test of the treatment effect. In most behavioral experimentation, differences among subjects make up the major contributor to variability in data (Kennedy & Bush, 1984). Correlations between the pretest and posttest greater than 0.20 result in ANCOVA power advantages. The description of the study are specified in the following sections.

Session Intervention Pattern

Seven intact middle school science classes were randomly assigned to one of the two groups. Students were not randomly assigned individually to groups A or B; assignment was done only at the class level. State law requires that the responsible teacher must monitor his/her students during class time. Although the experimental design would have been more powerful if students could have been randomly assigned to groups individually, the inability of teachers to monitor two distinct groups of students in two separate locations prohibited this randomization. Table 1 provides the experimental design for each group of the study. Group A teachers and students experienced Treatment 1, the simulation prior to the traditional laboratory experience, while Group B subjects received Treatment 2, the computer simulation posttraditional laboratory. The students for both the experimental groups were administered a pretest prior to the initial treatments and a posttest at the completion of the entire treatment protocol.

The general experimental design of the study followed the following format:

Table 1

Experimental Design for Each Group

Group A	O_1	X_1	X_2	O_2
Group B	O_1	X_2	X_1	O_2

O_1- Pretest
O_2 - Posttest
X_1- exposure to simulation
X_2- exposure to traditional lab

Instruments

The pretest and posttest (see Appendix A) used in the study were paper and pencil tests developed by the researcher. The same instrument was used for the pretest and the posttest to ensure equivalence for each group. Test construction was completed to examine the concept of creating an electrochemical cell on middle school students' knowledge of electrochemical concepts. Specifically, the test measured the concept of how an electrochemical cell works. Science teachers and students in science middle school classes used a computer simulation and traditional teaching and learning methodologies to study the physical science topic. Each test instrument consisted of the same three paper and pencil test items about the electrochemistry concept. Garnett and Treagust (1992) used a similar questioning format for their investigations of students' difficulties with basic principles about electrochemistry concepts. Brown and Clement (1991) suggested the use of qualitatively oriented and engaging lab exercises along with concrete examples.

Diagrams/illustrations were used in this study with science-content questions to present an electrochemistry concept problem. Each problem addressed a commonly held misconception involving a single electrochemistry concept. Participants were asked to make predictions and explain their reasoning for making the predictions. Two physicists who teach at the middle-school level reviewed the questions to evaluate their content validity as well as the level of difficulty of the items. The reviewers rated the tests as valid. They also rated the items as having equal difficulty, although each question addressed a different subtopic of the general concepts.

Description of the Test Items

There were three paper and pencil test items on the instrument. The items were open-ended questions, requiring students to generate a written free response. Brown and Clement (1991) emphasized students' oral and written explanation of their conceptual understanding as a method of teachers' isolating misconceptions. Answering essay questions requires physics students to review and reorganize their knowledge of the concept at hand in order to explain their understanding. Setting assignments that ask students to explain their reasoning in an essay style helps students clearly identify misconceptions (Renner, Abraham, Grzybowski, & Marek, 1992). Cashin (1987) stated that essay questions, like every assessment technique, have their advantages and limitations. The advantages are as follows:

- Essay questions can test complex learning outcomes not measurable by other means.
- The students can select, organize, and evaluate facts, ideas, and have the ability to apply, integrate, think critically, and solve problems.
- The questions can pose a more realistic task than multiple-choice and other objective items.
- The questions cannot be answered correctly by simply reorganizing the correct answer or by guessing.
- The questions can be constructed relatively quickly.

On the other hand, Cashin reported the limitations of essay test items as follows:

- Only a limited content can be sampled because it takes more time to answer and, therefore, has decreased validity.
- Scores can be influenced by the scorer's impression.
- The results can yield unreliable scores because of the differences in the grades assigned to essay questions by different scores.
- Essay tests are time consuming to score.

The questions in this study were derived from similar tests found in the misconception literature about the electrochemistry concept of how an electrochemical cell works. The test instrument focused on the specific concept of how a battery works. Question 1 addressed the subtopic of what elements must be in place to have a complete electrical circuit. In particular, the item measured how a battery needs a complete circuit, two dissimilar metals, and an electrolytic solution to create a voltage. Question 2 presented an item that required students to understand the effect of the size of an electrode on the voltage generated by a simple battery. Students were asked how changing the size of one electrode would affect the voltage produced by the cell. Question 3 addressed the topic of the necessity of having two dissimilar metals used as electrodes to generate a voltage. Students predicted how having two pieces of the same material type as electrodes would impact the voltage of the cell.

The electrochemistry concept test was given prior to the class activity to all participants. The researcher took adequate steps to insure the integrity of the test administration. Directions were read aloud by the classroom teacher to ask the participants to complete the pretest on their own without getting help from outside resources. Participants were advised (both orally and in the instructions for the test) that the evaluation is a program, and it is not an individual assessment that would be used in any way other than for this research. The students took 5 minutes to complete each test. The posttest followed the appropriate treatment. The researcher implemented the same procedure in the application of the posttest.

Variables

The following dependent variable was used in the study:

Posttest score—Electrochemistry concepts. This variable is defined as the students' score (0-4) on the pencil and paper instrument that was designed to measure the participants' knowledge of common electrochemistry concept. An evaluation rubric is provided in Appendix (D).

The following independent variables were used in the study:

The simulation. The goal of the Electric Potato computer simulation (see Appendix G) is to simulate the construction of an electrochemical cell to generate electrical voltage. The simulation is a part of the Lord Kelvin project to explain electrochemistry concepts to middle school students. In an attempt to simulate the real lab environment, the researcher designed a photo realistic, graphical representation of a science lab. Kulik (2002) reviewed six reports published since 1990 of controlled experiments using computer simulations in science teaching. The studies were carried out in high school courses in this country and abroad. The studies were short in duration; most examined a single simulation presented in one class period. The simulations were in biology, chemistry, earth science, and physics.

The Electric Potato simulation has interactive features that combine graphics, audio, and video. In order to complete the simulation, the user needs to use one or two potatoes and some common materials to create an electrochemical cell that produces electrical voltage. The simulation is combined with a voltmeter that measures the voltages being produced by connecting two potatoes, two lemons, and a combination of them, using alligator wires and different materials. The materials are ready to use in the simulation. The students' task is to construct different electrochemical circuits by dragging and dropping the material to the stage. The stage is where the experiment is constructed. After connecting the circuit to the voltmeter, the students will be able to see the electrical energy produced from the circuit in the voltmeter screen.

The Electric Potato simulation is a hybrid simulation because it is included with expository instructions, such as textual instruction about electrochemistry concepts, and a tutorial video to guide and help the students in completing the simulation.

Traditional laboratory experiment. This variable is related to an electrochemistry experiment that the students completed in the science laboratory. Handouts were provided to assist students in completing the experiment (see Appendices B and C). The teacher of the science class demonstrated the experiment in front of the students at the beginning of the class. Different combinations of materials were used to construct an electrochemical cell and measure the produced voltage. The materials used in this experiment consisted of potatoes, lemons, pennies, nails, alligator wires , and voltmeters. After completing the experiment, the teacher asked the students to conduct the experiment on their own.

The sequence of the instructional activity. This variable is related to when in the sequence of instructional events the simulation should be used.

Pretest scores. This variable is the students' score on the pencil and paper instrument that is designed to measure the participants understanding of a common electrochemistry concept.

Research Hypotheses

The following research hypotheses were tested on the effects of interventions on electrochemistry concepts knowledge:

Hypothesis 1. There are no significant differences between the pretest and post-test on test item #1 scores on knowledge of the electrochemistry concept involving the relationship between incomplete and complete conducting path for charges to move through a circuit for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #1 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 2. There are no significant differences between the pretest and post-test on the test item #2 scores on knowledge of the electrochemistry concept describing the relationship between surface area of the electrode and the voltage produced by an electrochemical cell for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #2 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 3. There are no significant differences between the pretest and post-test on test item #3 scores knowledge of the electrochemistry concept of two dissimilar metals being required as electrodes before an electrochemical cell may create a voltage for Group A, treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #3 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Experimental Procedures

Pretest administration. The electrochemistry concept pretest was given prior to each class activity to all participants. Directions were read aloud by the classroom teacher to ask the participants to complete the pretest on their own without getting help from outside resources. Participants were advised (both orally and in the instructions for the test) that the evaluation is a program, and it is not an individual assessment that would be used in any way other than for this research.

Treatment 1. Treatment 1 was defined as the presentation a computer simulation about an electrochemistry concept, followed by the exposure to a traditional laboratory experiment studying the same concept.

Treatment 2. Treatment 2 was defined as the presentation a traditional lab experiment about an electrochemistry concept followed by exposure to a computer simulation about the same concept.

Posttest. Immediately after the presentation of the treatment, the posttest was administered. All groups were given the posttest. Participants completed the posttest on their own without getting help from outside resources. All tests were coded for anonymity. Participants were reminded that the evaluation is a program and is not an individual assessment that would be used in any way other than for this research.

Ethical Assurances

The investigator made every attempt to comply with the standards for conducting research with human subjects. The investigator obtained parental consent for each student to participate in the project by way of informed consent form (Appendix E). This form described the nature and purpose of the study, the procedures to be followed, confidentiality of the research data, the benefits to be gained, and the fact that the participation in the research was voluntary. The consent form also clarified that student participation in the project would not affect their academic standing in any way. Additionally, the form offered the investigator's name and phone number to ensure accessibility to answer questions or concerns about the project. The form was distributed to all participants with a brief summary to enlist their support for the project, to answer any questions or concerns, and to emphasize the importance of returning the form signed by their parent. Approval was obtained from the University of Florida Institutional Review Board before proceeding with the research.

Data Analysis

Analysis of data was completed in the following manner. The study incorporated an analysis of covariance (ANCOVA) model that tested the data conformity on some predictor variable in the form of linear regression. An ANCOVA was used to compare the item means on the dependent variable adjusted for the influence of a covariate. The covariate (pretest) was used to adjust for initial differences between the treatment groups since random assignment within groups was not possible. Because the treatments were conducted on intact classes, an ANCOVA was used to analyze the data controlling for any systematic differences in ability level of students across these classes, following criteria from Williams (1979).

An ANCOVA was selected for use since it decreases error variance and increases the precision of the treatment effect estimates. This results in a more powerful test of the treatment effect. Correlations between the pretest and posttest greater than 0.20 results in ANCOVA power advantages over repeated measures ANOVA.

Using an ANCOVA for one between-subjects factor experimental design requires that a first test be made for the covariate by treatment interaction. If data conform to the ANCOVA model, the expected regression lines should be linear and parallel. When testing the interaction, parallel regression lines indicate rejecting the null hypothesis. The estimate of the treatment effect is indicated by the difference between the predicted posttest score of the students in the two groups who are "equivalent" on the pretest. A statistically significant difference suggests that one group would have outperformed the other group on the posttest if the groups had started out with the same pretest scores.

Separate ANCOVA analyses were conducted on each of the three questions on the test instrument. Cronbach's alpha was used to measure the reliability of the test questions. Cronbach's alpha measures the internal consistency of the test. The number of items on the test, item variance, and the variance of the composite affect the size of coefficient alpha. High reliability means that the questions of a test tend to pull together. Students who answered a given question correctly were more likely to answer other questions correctly. If a parallel test were developed using similar items, the relative scores of students would show little change. Low reliability indicates that the questions tend to be unrelated to each other in terms of which students answered them correctly. The resulting test scores may reflect particularities of the items or the testing situation more than the students' knowledge of the subject matter. Summary score reliability using Cronbach's alpha on instruments with few items generally is very low. Since the instruments used for this study only consisted of three items, Cronbach's alpha indicated poor reliability. Estimates of Cronbach's alpha were highest for both raters on the pretest—Rater 1 = 0.328 and Rater 2 = 0.361. The posttest reliability values were Rater 1 = 0.25 and Rater 2 = 0.217. The poor reliability data suggested that no summary score analysis should be conducted; instead, the data were analyzed at the individual question level.

Point bi-serial correlations were determined to indicate the relationship between the score on an individual item and the test as a whole. Point bi-serial correlations provide internal consistency measures and also gauge the discriminating power of an item. Table 2 reports the point bi-serial correlations for six item analyses. The low number of items on the test (three items) implies that lower point bi-serial correlations should be expected.

Whole-test interrater agreement was calculated for the instrument. Interrater reliability estimates are necessary when multiple observations are collected on each examinee by two or more raters. Pearson Product Moment correlations were determined to measure the scoring agreement on the entire test between the two raters. Item-by-item interrater agreement was also measured using Kendall's Tau-b. Kendall's Tau-b computes the difference between the concordant and discordant ranks among every pair of ratings.

Table 2

Point Bi-serial Correlations

		Point bi-serial correlations		Change in alpha when deleted	
Administration		Rater 1	Rater 2	Rater 1	Rater 2
Pretest	Item 1	0.142	0.203	0.346	0.294
	Item 2	0.225	0.237	0.156	0.212
	Item 3	0.154	0.142	0.151	0.098
Posttest	Item 1	0.154	0.142	0.151	0.098
	Item 2	0.058	0.065	0.336	0.258
	Item 3	0.207	0.141	0.002	0.088

Table 3

Pearson Product Moment and Kendall's Tau Correlations

	Pretest		Posttest	
	PPM	Kendall's tau-b	PPM	Kendall's tau-b
Item 1	0.938	0.870	0.944	0.806
Item 2	0.964	0.905	0.907`	0.796
Item 3	0.889	0.857	0.917	0.864

CHAPTER 4
RESULTS

The purpose of this study was to investigate the effectiveness of a computer simulation in terms of increased student conceptual understanding based on the instructional sequence, that is, as to when is the most appropriate time for a simulation to be presented to improve student understanding of a science concept. The research question outlined in the previous chapter centered on whether the instructional sequence of a computer simulation and a traditional science laboratory can effectively reduce common physical science content knowledge misconceptions.

This chapter presents the descriptive statistics of the sample, and the results of the ANCOVA used to test the hypotheses. The chapter concludes with a summary of major findings.

Descriptive Statistics of the Sample

Participants were selected for the study from a sample chosen by the investigator as a representative sample of public school students and teachers in North Florida. All participants in the study came from Gainesville, Florida. Participants from middle schools in Alachua County district completed the study. The total number of participants was 176 students. The first school was a rural middle school, which has a total of 549 students in Grades 6 to 8. The pupil/teacher ratio for the school is 17 students per teacher.

The second school was a suburban middle school, which has a total of 1,007 students and a pupil/teacher ratio of 21. Table 4 depicts the demographic information for both schools

Table 4

Demographic Data for the Experimental Schools

School	Total students	White	Black	Hispanic	Asian	Indian	Pupil/teacher ratio Grades 6 to 8
Rural	549	72.5%	24.2%	1.5%	1.3%	0.5%	17
Suburban	1,007	59.6%	29.2%	7.1%	3.8%	0.4%	21

Group Formation

Seven classes participated in the study, with a total number of 176 students. The researcher randomly assigned seven intact middle school classes to two experimental groups (Group A and Group B). Students were not randomly assigned individually to Groups A or B; assignment was done only at the class level.

Treatment

All pretests and posttests in this study were paper and pencil tests (see Appendix A). Teachers and students in science middle school classes used a computer simulation and traditional teaching and learning methodologies to study basic electrochemistry concepts regarding how an electric circuits work and what kinds of materials can be used to generate voltage. Group A started with a pretest, and after completing the pretest, the students started the computer simulation in the computer lab. After completing the simulation, the students started the lab experiment. The posttest was administered after the completion of the lab experiment. Group B started with a pretest; after completing the pretest, the students started the experiment in the lab. After the completion of the lab experiment, the students started the simulation in the computer lab. The posttest was administered after the students finished the computer simulation.

Hypothesis Testing

The following research hypotheses were tested for the effects of interventions on electrochemistry concepts knowledge:

Hypothesis 1. There are no significant differences between the pretest and post-test on test item #1 scores on knowledge of the electrochemistry concept involving the relationship between incomplete and complete conducting path for charges to move through a circuit for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #1 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 2. There are no significant differences between the pretest and post-test on the test item #2 scores on knowledge of the electrochemistry concept describing the relationship between surface area of the electrode and the voltage produced by an electrochemical cell for Group A treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #2 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Hypothesis 3. There are no significant differences between the pretest and post-test on test item #3 scores knowledge of the electrochemistry concept of two dissimilar metals being required as electrodes before an electrochemical cell may create a voltage for Group A, treated with the intervention of using the simulation, then completing the traditional lab experiment, and the test item #3 scores of Group B treated with the intervention of completing traditional lab experiment then using the simulation, as assessed by an analysis of covariance statistical procedures at the 0.05 level of significance (alpha).

Analysis of covariance (ANCOVA) was used to compare means on the dependent variable (test scores of knowledge of electrochemistry concepts) adjusted for the influence of a covariate (pretest). The ANCOVA combines features of analysis of variance and ordinary least squares regression. The analysis of covariance extends the ANOVA by including information on some predictor, often a pretest measure, in the form of the linear regression. Using a covariate can adjust for initial differences between treatment groups in the event that random assignment is not possible. The ANCOVA decreases error variance (i.e., the standard errors with an ANCOVA are usually smaller than an ANOVA, often substantially), increasing the precision of the treatment estimates. This results in a more powerful test of the treatment effect. The power advantages of an ANCOVA accrue to the extent that the pretest and posttest are correlated.

Separate ANCOVA analyses were conducted on each of the three questions. Summary score analyses were not reported due to poor reliability of limited item instruments as discussed in the previous chapter. Descriptive statistics for pretest and posttest scores for all three questions are presented in Table 5. The ANCOVA results for the order effect by each item are presented in Tables 6, 7, and 8, respectively.

Table 5

Descriptive Statistics of the Means and Standard Deviation by Question for Pretest and Posttest Scores

	Pretest						Posttest					
	Sim-Lab			Lab-Sim			Sim-Lab			Lab-Sim		
	N	M	SD	N	M	SD	N	M	SD	N	M	SD
1	79	1.044	1.328	97	1.036	1.375	79	3.544	0.906	97	3.242	1.362
2	79	1.753	1.382	97	1.753	1.305	79	2.646	1.133	97	2.485	1.081
3	79	0.633	1.009	97	0.711	0.875	79	2.335	1.495	97	2.299	1.274

Significant at the .05 level

Table 6

ANCOVA Results for Order Effect for Item #1

Source	DF	Type III SS	Mean square	F value	Pr > F
Order	1	6.38048237	6.38048237	5.00	0.0267
avgpreq1	1	17.79296906	17.79296906	13.93	0.0003
avgpreq1* ORDER	1	2.46326684	2.46326684	1.93	0.1667

Significant at the .05 level

Table 7

ANCOVA Results for Order Effect for Item #2

Source	DF	Type III SS	Mean square	F value	Pr > F
ORDER	1	0.01068655	0.01068655	0.01	0.9125
avgpreq2	1	60.14485672	60.14485672	68.14	<0.0001
avgpreq2* ORDER	1	0.88336044	0.88336044	1.00	0.3185

Significant at the .05 level

Table 8

ANCOVA Results for Order Effect for Item #3

Source	DF	Type III SS	Mean square	F value	Pr > F
Order	1	0.42660937	0.42660937	.025	0.6207
avgpreq3	1	27.82750280	27.82750280	16.04	<0.0001
avgpreq3* ORDER	1	3.11206411	3.11206411	1.79	0.1823

Significant at the .05 level

Question 1. Question 1 measured the degree of understanding of the electrochemistry concept by using an ordinal scale, with "0" being limited understanding or the presence of a misconception to "4" being satisfactory understanding with no misconceptions evident. In order to show understanding of the electrochemistry concept, students were expected to identify that the voltmeter would not show a positive voltage reading when the electrochemical cell had an incomplete conducting path. In examining the first question, the PPM correlation between pretest scores and scores on the posttest (averaged across the two raters) on Question 1 is $r = .29$. The covariate by order effect is not significant, $F(1, 172) = 1.93$, $p = .1667$. The model, including the interaction term, accounts for only 11% of the variance in scores on the posttest ($R^2 = .1076$).

Results of refitting the model with constraint that the slopes are equal are depicted in Figure 1. Adjusted means are presented in Table 9. Table 10 shows the ANCOVA with covariate by treatment interaction removed. While the pretest is a significant predictor of the posttest score on Question 1, $F(1,173) = 15.62$, $p < .0001$, the order effect is not significant testing at $a = .05$, $F(1,173) = 3.05$, $p = .0824$. There does,

Table 9

Adjusted Means

	Order	
Question	Lab-Sim	Sim-Lab
1	3.243	3.543
2	2.485	2.645
3	2.284	2.354

Table 10

Rerun of ANCOVA Taking Out the Covariate by Treatment Interactions for Question #1

Source	DF	Type III SS	Mean square	F value	Pr > F
Order	1	3.91790268	3.91790268	3.05	0.0824
Avgpreq1	1	20.04744967	20.04744967	15.62	0.0001

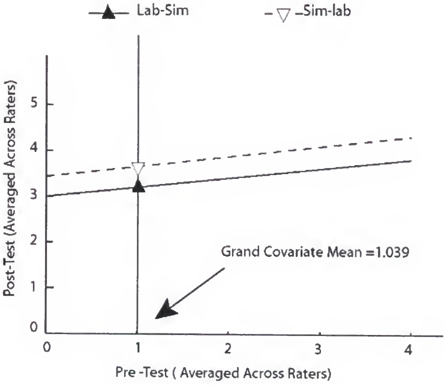


Figure 1. Regression lines with equal slopes and adjusted means—Question #1.

however, appear to be a trend toward significance—the effect may be small and the sample is not large enough to demonstrate it.

The results indicated that the order of presentation did not significantly impact the reduction of the students' misconceptions about the electrochemistry concept involving the relationship between incomplete and complete conducting path for charges to move through a circuit as demonstrated by the performance of the students on the assessment instruments. Comparing the pretest to posttest mean scores with respect to gains in performance did indicate that the students improved their conceptual understanding of the complete circuit concept after completing both the simulation and laboratory interventions; however, no order effects were evident.

Question 2. Question 2 used the same ordinal scale to measure the degree of understanding of a related electrochemistry concept: As the surface area of an electrode increases, the voltage produced by the electrochemical cell increases. Student demonstrated attainment of the concept by noting that a larger nail used in conjunction with two copper pennies would produce a larger voltage than a small nail combined with one penny. The PPM correlation between pretest scores and posttest scores (averaged across the two raters) for Question 2 is $r = .53$. The covariate by order effect is not significant, $F(1, 172) = 1.00$, $p = .3185$. The model, including the interaction term, accounts for approximately 29% of the variability in scores on the posttest ($R^2 = .2887$).

Results of refitting the model and constraining the slopes to be equal are depicted in Figure 2. Adjusted means are presented in Table 9. Table 11 shows the ANCOVA with covariate by treatment interaction removed. While the pretest is a significant predictor of

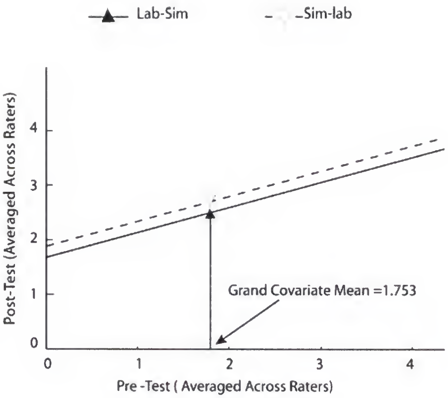


Figure 2. Regression lines with equal slopes and adjusted means—Question #2.

Table 11

Rerun of ANCOVA Taking Out the Covariate by Treatment Interactions for Question #2

Source	DF	Type III SS	Mean square	F value	Pr > F
Order	1	1.12547144	1.12547144	1.28	0.2604
Avgpreq2	1	59.59506205	59.59506205	67.51	0.0001

posttest score on Question 2, F (1,173) = 67.51, p < .0001, the order effect is not significant, F (1,173) = 1.28, p = .2604.

The results indicated that the order of presentation did not significantly impact the reduction of the students' misconceptions about the electrochemistry concept describing the relationship between surface area of the electrode and the voltage produced by an electrochemical cell as demonstrated by the performance of the students on the assessment instruments. Comparing the pretest to posttest mean scores with respect to gains in performance did indicate that the students improved their conceptual understanding of the complete circuit concept after completing both the simulation and laboratory interventions.

Question 3. The “0” to “4” ordinal scale was again used in Question 3 for measuring the understanding of another subtopic related to electrochemical cells. Question 3 addressed the common student misconception regarding the nature of the conducting material required for the generation of a potential difference. The correct concept states that two dissimilar metals are required as electrodes before an electrochemical cell may create a voltage. Students showed proficiency of the concept by noting that a cell with two electrodes made of the same metal (two nails or two pennies) would not create a voltage when properly connected in an electrochemical cell. The pretest/posttest correlation (averaged across the 2 raters) for Question 3 is $r = .29$. The covariate by order effect is no significant, $F(1, 172) = 1.79$, $p = .1823$. The model, including the interaction term, accounts for only 9% of the variability in scores for question 3 on the posttest ($R^2 = .0962$).

Results of refitting the model with the constraint that the slopes are equal are depicted in Figure 3. Adjusted means are presented in Table 9. Table 12 shows the ANCOVA with covariate by treatment interaction removed. While the average pretest score is again a significant predictor of average posttest score on question 3, $F(1,173) = 16.40$, $p < .0001$, the order effect is not significant, $F(1, 173) = .12$, $p = .7256$.

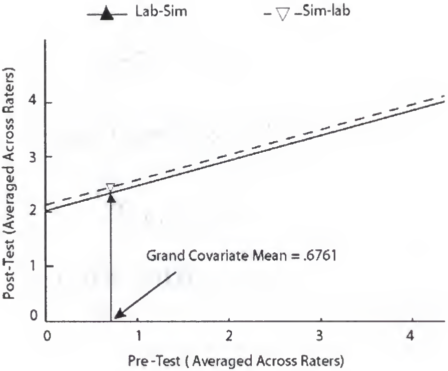


Figure 3. Regression lines with equal slopes and adjusted means—Question #3.

Table 12

Rerun of ANCOVA Taking Out the Covariate by Treatment Interactions for Question #3

Source	DF	Type III SS	Mean square	F value	Pr > F
Order	1	0.21545724	0.21545724	0.12	0.7256
Avgpreq3	1	28.59867444	28.59867444	16.40	<.0001

The order of the presentation of the simulation and laboratory did not significantly affect the students' understanding of the dissimilar metal requirement for proper performance of an electrochemical cell. Comparing the pretest to posttest mean scores with respect to gains in performance did indicate that the students improved their conceptual understanding of the dissimilar metals concept after completing both the simulation and laboratory interventions.

Summary

This study investigated the order effects of presenting a computer simulation versus a traditional laboratory experience on middle school grade students' conceptual understanding of an electrochemistry topic: the components required for an electrochemical cell. The first hypothesis examined the impact of the order of presentation of a simulation and a laboratory experience on students' understanding of the relationship between complete and incomplete conducting paths. Examining the first hypothesis, the adjusted mean scores from the pretest to the posttest did not support a difference due to order effects. Hypothesis two examined the relationship between surface of an electrode and voltage created, while hypothesis three investigated how two dissimilar metals are required as electrodes in an electrochemical cell. All three hypotheses' test data reflected a general trend of supporting the thesis proposed by the researcher, yet no statistical significance was established. In the final chapter the results are discussed and related to the literature. In addition, conclusions, and implications of this study and recommendations for further research are presented.

CHAPTER 5
CONCLUSIONS

This study investigated how the instructional sequence of a computer simulation and a traditional laboratory impacted middle grade students' conceptual understanding of an electrochemistry topic. The first hypothesis addressed the difference in pretest and posttest scores on item #1, which measured the relationship between complete and incomplete conducting paths, between the groups who experienced the different instructional sequences of a simulation and a traditional laboratory. Examining the first hypothesis, the adjusted mean scores of item one from pretest to posttest did support a slight difference due to order effects. However, using ANCOVA, these effects were not found to be statistically significant. The second hypothesis addressed the difference in pretest and posttest scores on item #2, which examined the link with surface area of electrodes and voltage produced by an electrochemical cell. The third hypothesis addressed the differences in pretest and posttest scores for item #3. This hypothesis investigated the required material components of an electrochemical cell. Hypotheses 2 and 3 test data, for items 2 and 3 respectively, also reflected this general trend of supporting the thesis proposed by the researcher, yet no statistical significance was established.

Discussion

The results of this study did not statistically support the theory that prior use of a simulation before the traditional lab can improve learning. However, the treatment group that completed the simulation activities before the actual hands-on lab performed slightly better on the achievement posttest than the other group.

In a number of studies (Andre & Haselhuhn 1995, Brant et al. 1991), simulations used before either didactic instruction or another alternative educational experience yielded more effective learning than simulations used after. The reason for this was brought forth by Thomas and Boysen (1984), who speculated that one use of simulations is to provide prior experience that helps students understand later instruction. Scholars have wondered as to how such simulated prior experiences can lead to increased understanding. One possibility uses Tulving's (1972) ideas of episodic and semantic memory. In Tulving's view, episodic memory contains memories for one's personal experiences, whereas semantic memory contains more generalized and abstracted symbolic knowledge. Episodic memory and semantic memory are experienced differently, and the recall from one or the other seems to activate different portions of the brain. Carlsen and Andre (1992) argued that experience stored in episodic memory is related to symbolic knowledge stored in semantic memory and that the two memory stores interact to produce effective knowledge. In the present case, prior use of simulation may have led to episodic memories that helped students make sense of subsequent complex instructional events. When students are presented with complex didactic instruction after a simulation, as in Brant et al. (1991) and Andre and Haselhuhn (1995), they can refer to their episodic memory of the simulation to help make sense of the instruction. When presented with a complex concept like electrochemistry, the prior use of the simulation may have laid down episodic memories that help students discriminate and identify particular components of the experiment. As one student who took the simulation first stated, "A computer makes it easy to complete the lab experiment." While he was conducting the lab experiment, another student said, "Like the computer, when we use different material, there is voltage."

The sequence in which learning occurs influences the stability of cognitive structures (Ausubel, 1968). New knowledge is made meaningful by relating it to prior knowledge, and optimization of prior knowledge is done through sequencing. According to Gokhale (1991), simulations used prior to formal instruction build intuition and alert the student to the overall nature of the process. When used after formal instruction, the program offers the student an opportunity to apply the learned material. Since no significant differences were found due to the order effects, yet cognitive gains from the pretest to the posttest were evident, perhaps both of Gokhale's ideas were supported by this study.

What is not clear is why a simulation used after traditional instruction has less of an effect. It may be that students are unable to form a good memory of the prior instruction because it is too complex and thus cannot relate the subsequent simulation to it. Another possible alternative is that students believe they already know what the simulation covers and attend less to it. As one student stated in all his responses, "Same as the lab experiment." The present study cannot provide an explanation but suggests that this is another important line of research. There is a second possible explanation for the present results. The simulation may have sufficiently simplified the complex concept of electrochemistry and directly taught students the procedure to follow in doing the lab experiment. Thus, the slightly better performance observed in the simulation before the lab experiment group may have occurred because that group simply had been taught how to do the experiment while the other group was engaged in discovery learning while doing the experiment.

Implications

The results of this study suggest that simulations, when used before or after traditional laboratory activities can lead to enhanced understanding when learning is measured by paper and pencil tests. Further, the research suggests that simulation used before other educational experiences can facilitate learning as well as or slightly more than simulations used after other experiences.

One particularly important finding in this study is that simulations can be educationally sound and useful when used in conjunction with traditional science laboratories and other activities. In science education classroom simulations provide an opportunity to apply the scientific method to the solution of problems by providing learners with a rich and variable learning environment in which they can master skills and content, develop understanding of concepts, explore various cause-and-effect relationships, and quickly test multiple hypotheses. The capability of computer simulations to transform (in real time) data from experiments into a graph, which is a powerful form of information presentation, is something that has not been possible in the past (Adams & Shrum, 1990). Real-time graphing may be one of the key elements in helping students construct science concepts and graphing skills because it provides opportunities for students to connect the production of the graph with the physical manipulation of the materials (Adams & Shrum, 1990). Real-time graphing also provides an opportunity for students to modify the initial or experimental conditions and immediately see the effect of their modification on the resulting graph (Krajcik, 1992). The combination of the abstract graphing ability of the computer-based laboratory technology with the real world experiment allows for what Adams and Shrum (1990) called the "immediate abstraction." Students can answer "what if" questions rather than just answer questions supplied with the laboratory manual. The immediate abstraction is the result of the process where the student bridges the gap between concrete and formal operations. The flexibility of the computer-integrated environment gives students more of an opportunity to plan and design their own experiments.

It also made clear that additional research is needed to understand more fully the educational impact of simulations in science education. Computer simulations can display some distinctive advantages when used as an alternative to the traditional classroom. The first is cost effectiveness and cost efficiency. Some potential problems exist in public schools such as the availability, cost, and storage of some materials required for conducting lab experiments. In the case of the electric potato laboratory experiment (used in this study and as described in Chapter 3), the teacher had to prepare a list of items to conduct the experiment such as potatoes, lemons, wires, large nails, small nails, pennies, and voltmeters. These kinds of materials could be damaged from repetitive use by different teachers and classes; therefore, time and money is needed to replace the damaged materials. By using simulations instead, money is saved because the purchase of computer simulations is a one-time event, and they can be used repeatedly over long periods of time compared to the cost of purchasing these materials every few months. In addition, a computer simulation of a phenomenon runs in minutes instead of the several hours or days sometimes required by traditional physical methods. Along with giving students greater efficiency, it enables them to investigate more variables (Coleman, 1997). Computer simulations can provide teachers with a time-efficient, cost-effective instructional strategy that can provide students with the opportunity for critical thinking, problem solving, and self-monitoring skills to clarify their misconceptions.

One direction for future research is to explore the time to complete tasks when simulations are used compared with traditional instruction. The researcher anecdotally notes that students who experienced the simulation before the traditional laboratory experience completed the laboratory more quickly and with apparent greater confidence than the other students. The simulation appeared to clarify the task to be completed in the laboratory much like a diagram accompanying the procedures for an experiment. Additional research is needed to assess quantitatively the role of simulations in clarifying traditional laboratory experiments.

A second issue to be explored is how individuals and groups interact differently with simulations. There has been some debate among scholars as to whether simulations work equally effectively for the different genders, for students with different personality, cognitive style characteristics, for students from minority groups, or for students from a variety of cultures. Another issue is the long-term use of simulations. This study involved short-term use of simulations. It has been argued as to whether simulations have the same educational effects when they are integrated into semester or year-long course sequences and are a typical part of the student's day. These questions can only be answered by additional research.

A last area of needed follow-up involves the use of the paper and pencil test instrument format when conducting investigations using a computer simulation. A more appropriate format for the collection of assessment data may be the computer simulation itself instead of changing modes, which requires the user to write his/her responses on paper. Students with poor English language written skills may be unfairly punished using a paper and pencil written format. An on-screen assessment instrument may alleviate or reduce some of these potential problems.

The study has several limitations to generalization. As reported in Chapter 1, one limitation was the geographic population from which the sample was drawn (North Florida public middle schools). Another limitation was the age of the participants included in the sample (Grades 6 and 7). Caution should be made not to overgeneralize to all public schools grades.

Another factor concerning the limitations was the instrument used in the study. The instrument consisted of three test items drawn from other researchers in the area of identifying and correcting electrochemistry misconceptions. The instrument did not use a multiple choice, true/false, or other short answer response format. The brief, open-ended tests were used to explore students' understanding of a specific electrochemistry concept.

The 3-item test was selected because of the limited nature of the topic investigated by the students. A 50-item multiple-choice test can effectively assess multiple concepts; however, the many-item format does not efficiently lend itself to limited topic measurements. Open-ended, brief-item formats do provide a mechanism for evaluating students' conceptual attainment. Current science learning theories focus on presenting and measuring few topics instead of a wider breadth of coverage. The study's design and measurement instruments attempted to reflect this idea.

Summary

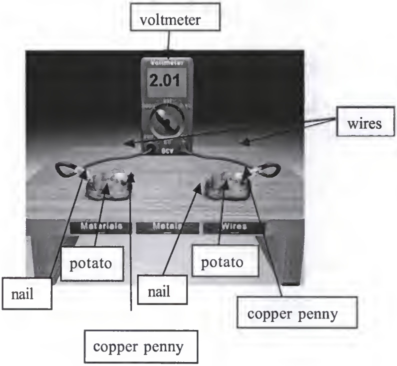
This study investigated how the instructional sequence of a computer simulation and a traditional laboratory impacted middle grade students' conceptual understanding of an electrochemistry topic. The results of this study did not statistically support the theory that prior use of a simulation before the traditional laboratory can improve learning. However, the treatment group that completed the simulation activities before the actual hands-on lab performed slightly better on the achievement posttest than the other group. The finding of this study suggests that simulations used before or after traditional laboratory experiences can lead to improved student performance when learning is measured by paper and pencil tests. Further, the study suggests, although the data do not yield statistical significance, that simulations used before other educational experiences can facilitate learning slightly better than simulations used after other experiences. The present study suggests that simulations can be educationally sound and useful when used in conjunction with traditional science laboratories and other activities; it also made clear that additional research regarding the educational outcomes is needed to clarify the relationship between the variables and the educational impact of simulations in science education. One direction for future research is to explore the time to complete tasks when simulations are used compared with the traditional instruction in question. A second issue to be explored is how individuals and groups interact differently with simulations. Often scholars have argued that simulations work equally effectively for the different genders, for students with different personalities, for cognitive style characteristics, for students from minority groups, or for students from a variety of cultures. These questions can only be answered by additional research.

APPENDIX A
PRETEST/POSTTEST

Name____________________

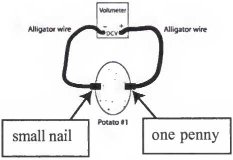
Directions: Thank you for participating in my study. I thank you in advance for completing the pretest, experiments and posttests. Please remember that your grade will *not* be impacted by the results of this study. Since you'll be completing a series of three short tests, I do need your name so I can measure how well you did on each test. Please write your name in the space at the top of this page. After you write your name, please complete the pretest.

1. The picture of the simulation below has a major flaw. What is it about the setup of the materials that tells you that what appears is *not* possible? Please write your answer in the space provided.

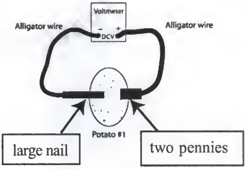


Please write your answer in this space.

2. Which experimental setup, A or B, produces the greater voltage? Or would both A and B produce the same voltage? Please explain your answer in the space below.



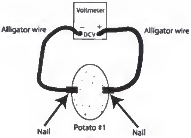
Setup A



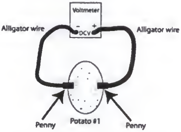
Setup B

Please write your answer in this space.

3. Which experimental setup, C or D, produces the greater voltage? Or would both C and D produce the same voltage? Please explain your answer in the space below.



Setup C



Setup D

Please write your answer in this space.

APPENDIX B
THE ELECTRIC POTATO LAB HANDOUT

What you'll do

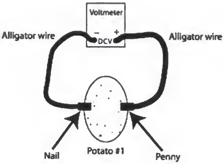
In this experiment you'll use some common materials to create a battery. You'll use a voltmeter to find the best combination of materials to make the greatest voltage.

Materials

Four 3-d galvanized nails (must be zinc coated), two 12-d galvanized nails (must be zinc coated), three alligator clip/wire units, four copper pennies, two large baking potatoes, one lemon.

Creating the potato battery

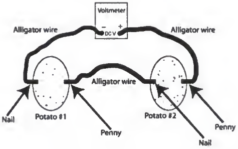
1. Place one potato on your desk.
2. Insert one penny into one end of a potato.
3. Insert one small nail into the potato, placing the nail as far from the penny as possible.
4. Use the alligator wires to connect the nail and penny as specified in the wiring diagram.
5. Use the voltmeter to measure and record the voltage produced by this setup in the data table.



Does the number of potatoes affect the voltage of a battery?

1. Place two potatoes on your desktop about 6 inches apart.
2. Insert one penny into the end of each potato.
3. Insert one small nail into each potato, placing the nails as far from the pennies as possible.

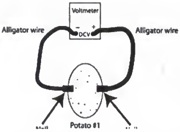
4. Use the alligator wires to connect the nails and pennies as specified in the wiring diagram.
5. Use the voltmeter to measure and record the voltage produced by this setup.



……

Will an all nail battery work?

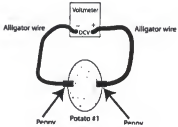
1. Place one potato on your desk.
2. Insert one small nail into the end of a potato.
3. Insert another small nail into the other end of the potato, placing the nail as far from the first nail as possible.
4. Use the alligator wires to connect the nails as specified in the wiring diagram.
5. Use the voltmeter to measure and record the voltage produced by this setup.



……

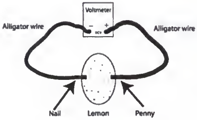
Will an all copper battery work?

1. Place one potato on your desk.
2. Insert one small nail into the end of a potato.
3. Insert another copper penny into the potato, placing the penny as far from the first penny as possible.
4. Use the alligator wires to connect the wire as specified in the wiring diagram.
5. Use the voltmeter to measure and record the voltage produced by this setup.



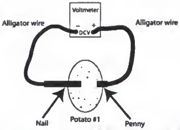
Can other materials be used in place of potatoes?

1. Place a lemon on the desktop.
2. Insert one penny into the end of a lemon.
3. Insert one small nail into the lemon, placing the nail as far away from the penny as possible.
4. Use the alligator wires to connect the nail and copper penny as specified in the wiring diagram.
5. Use the voltmeter to measure and record the voltage produced by this setup.



Finding out the effects of increasing the surface area of the metal on voltage.

1. Place one potato on your desk.
2. Insert one penny into the end of a potato.
3. Insert one large nail into the potato, placing the nail as far from the penny as possible.
4. Use the alligator wires to connect the nail and copper penny.
5. Use the voltmeter to measure and record the voltage produced by this setup.



APPENDIX C
THE ELECTRIC POTATO DATA SHEET

Name ____________________

Method	Voltage (volts)
Getting Started	
1 Potato 2	
All Nails	
All Pennies	
Lemon	
Surface Area	

Questions for you to think about

1. Which battery setup produced the greatest voltage? Explain why this setup worked so well.

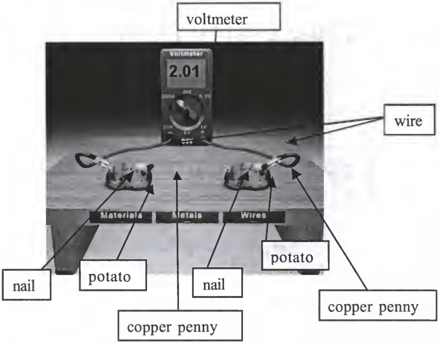
2. Which battery setup produced the least voltage? Explain why this setup worked so poorly.

3. Many people think that the more potatoes used, the greater the voltage produced. This is not the case; instead, another factor accounts for the greater voltage produced by the two potatoes versus the one potato. What factors do you think result in the greater voltage with the two-potato system?

APPENDIX D
EVALUATION RUBRIC

Question 1

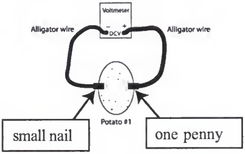
The picture of the simulation below has a major flaw. What is it about the setup of the materials that tells you that what appears is *not* possible? Please write your answer in the space provided.



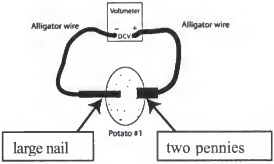
Scientific answer	Score	Sample students' responses
The voltmeter displays a voltage of 2.01 volts, yet a connecting wire is missing between the two electrodes (and between the two potatoes). A complete path is needed for current to follow in the circuit.	0	- the nails and pennies need to be on the same side - there is nothing wrong - nothing
	1	- the home made battery would not make that much electricity
	2	- it not suppose to be voltage
	3	-the voltmeter is not correct
	4	- there is no alligator wire between the potatoes - need wire in the middle

Question 2

Which experimental setup, A or B, produces the greater voltage? Or would both A and B produce the same voltage? Please explain your answer in the space below.



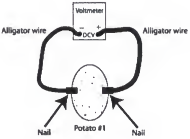
Setup A



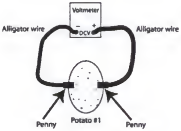
Setup B

Scientific answer	Score	Sample Students' responses
Setup B will produce more voltage. This is because there is a greater surface area (and more material) on the electrodes in setup B as noted by a large nail and two pennies. As surface area increases, voltage produced increases.	0	- both A and B - set A because B has too much metal - I have no clue
	1	- the large nail is the one that will work - I think it would be both A+B, although the setup B is bigger because they both have alligator wire
	2	- setup B because it has more volts - setup B because the potato is bigger than the other
	3	- B Large nail 2 pennies - setup B because more can flow through, more energy can be produced to a greater voltage.
	4	- setup B would generate more voltage, because the nails are larger - setup B would create more voltage because there is more electricity created with more metal.

Question 3
Which experimental setup, C or D, produces the greater voltage? Or would both C and D produce the same voltage? Please explain your answer in the space below.



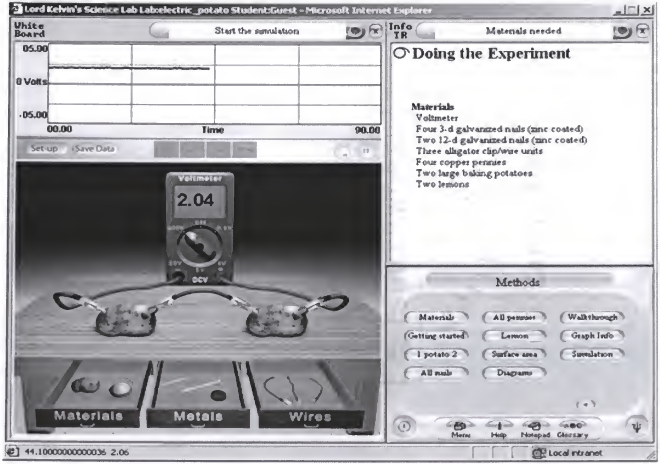
Setup C



Setup D

Scientific response	Score	Sample Students' responses
Both setups will produce the same voltage, zero. This is because an electrochemical cell must have two dissimilar metals that act as electrodes. No potential difference can be produced from electrodes composed of the same metal type.	0	- I don't know - setup C because it has both nails
	1	- they are both the same because they are the same metal
	2	- C and D setup are the same, so the voltage would be the same, greater or smaller it would be the same - the both would give the same because it is not mixed up
	3	- I think both of them will have the same because they are both metals. - same because there is no voltage
	4	-Their both the same nail and nail is .0 and an penny plus another penny equal .0 too. - voltmeter D and C will be the same because nails equal 0.00 and also pennies

APPENDIX E
ELECTRIC POTATO SIMULATION



Doing the Experiment

Materials
Voltmeter
Four 3-d galvanized nails (zinc coated)
Two 12-d galvanized nails (zinc coated)
Three alligator clip/wire units
Four copper pennies
Two large baking potatoes
Two lemons

APPENDIX F
COMPUTER LAB HANDOUT

Electric Potato

Student name
Period Date

1. Click on the "*Challenge*" button to get started. After you have read the challenge, click on the "*Methods*" button.

2. Click on "*Getting Started*" and follow the directions for creating a potato battery.

3. Record your data and answers to the following questions in the space below. Click on the buttons on the Psi tool like, 1 Potato 2, all nail, and all penny, to get directions for completing that part of the activity.

Getting Started

- Can a potato battery be used to create a voltage?

1 Potato 2

- Does increasing the number of potatoes affect the voltage produced?

All nail

- Will a potato and only two nails produce a voltage?

All penny

- Will a potato and only two pennies produce a voltage?

Inquiries in science

APPENDIX G
INFORMED CONSENT FOR PARTICIPATING IN A STUDY

My name is Ebraheem Alkazemi and I am a graduate student working on my doctoral degree in Educational Technology at the University of Florida. The purpose of this form is to solicit your consent for your child to participate in a study. The purpose of the study is to compare how students learn about a science topic using a traditional laboratory approach versus a computer simulation. There are no anticipated benefits or risks to you for participating in this study.

Your child's grade in his/her science class will not be affected in any way whether s/he participates in this study or chooses not to participate. Your child's identity will be kept confidential to the extent provided by law.

The experiment should take about 60-90 minutes to complete. You and your child will not be compensated for completing or taking part in the study. Students who do not take part in the study will complete their normal teacher-assigned class work. I thank you in advance for helping me conduct my research that will improve students' learning of science in the future.

Before, during and after completing the experiment your child will be asked questions about the science content covered in the lesson. Your child does not have to answer any questions s/he does not wish to answer. If at any point during the experiment your child chooses to discontinue participating in the experiment, s/he may do so without any consequences.

If you have any questions regarding this study, please feel free to call or write me at:
Ebraheem Alkazemi
School of Teaching and learning
Department of Educational Technology
University of Florida
e-mail address:Ebraheem@athena-group.com
home: (352) 376-1706
Cell phone: 352-870-6933

Or you can contact my supervisor at University of Florida
Dr. Jeff Hurt, Associate Professor,
College of Education, School of Teaching and learning,

Phone:(352) 392-0705 ext 258 Fax (352) 392-9193
e-mail: jhurt@coe.ufl.edu
G509 Norman Hall, PO Box: 117048
Gainesville, FL 32611-7048

Contact the following office if you have any questions or concerns about your child's rights as a participant:

UFIRB Office
Box 112250
University of Florida
Gainesville, FL 32611-2250

I have read the procedure described above. I agree to allow my child to participate in the procedure and I have received a copy of this description.

____________________	____________________
Student Name	*Date*
____________________	____________________
Parent Signature	*Parent Signature*

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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